



## Possibility of Using Agrivoltaics in Vineyards in The Island of Crete, Greece

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**ABSTRACT:** The clean energy transition in Europe and worldwide requires the generation of electricity from zero-carbon energy sources including solar and wind energy. Solar photovoltaics are in the forefront of clean energy technologies used in the decarbonization of the global power system. Agrivoltaics is an emerging solar energy technology that allows the dual production of electricity and agricultural products in the same land area. The possibility of installing agrivoltaics in vineyards in the island of Crete, Greece has been studied. Several published papers assessing the use of agrivoltaics in vineyards in several countries have been reviewed while their benefits and challenges have been stated. It has been estimated that installation of agrivoltaics in vineyards in Crete covering 1% of their surface with coverage ratio at 15% and 30% can generate electricity meeting 2.6% and 5.2% of Crete's annual electricity demand respectively. The generated electricity can cover the electricity demand of 20,800 and 41,600 households respectively in Crete. Although there are not sufficient data assessing the use of agrivoltaics in vineyards it is concluded that, under specific conditions, they have many benefits regarding the dual production of electricity and grapes. Our results indicate that installation of agrivoltaics in Cretan vineyards, under limited shading, can offer an additional income to farmers improving the growth and yield characteristics of the cultivated vines. Our result could be useful to many stakeholders of Cretan viticulture.

**KEYWORDS:** Agrivoltaics, Crete-Greece, Electricity, Microclimate, Solar photovoltaics, Vineyards

### 1. INTRODUCTION

The dual production of food and energy is gaining interest worldwide due to the importance of these two resources. The current climate crisis and the achievement of the net-zero emissions target increase the efforts to achieve higher yield in land resources. The installation of solar photovoltaic (Solar-PV) systems in cultivated land – agrivoltaics - without reducing the photosynthetic process in the crops is gaining interest and many studies and pilot systems have been developed worldwide (1),(2), (3), (4), (5), (6). However, agrivoltaics should not create enough shading to hinder the development and the yield of the cultivated plants (13-2024). Existing studies indicate that use of agrivoltaics in vineyards has many benefits including dual production of food and energy, protection of the crop against extreme weather events, reduction of the water need of vines, offering an economic benefit to farmers (8). The social perception of local societies regarding their installation in vineyards has been investigated (9). Winemaking is an old traditional industry in the island of Crete, Greece while the island has abundant solar energy resources which are currently used for power generation (30-2009).

*The aim of the current study is to investigate the possibility of using agrivoltaics in vineyards in Crete estimating the generated electricity.*

The text is structured as follows: After the literature survey the use of solar-PVs in Crete and the cultivation of vines in the island are stated. In the next two sections the use of agrivoltaics is described and the possibility of using agrivoltaics in vineyards in Crete is analyzed. The text ends with discussion of the findings and the conclusions drawn.

The research is innovative since there are no similar studies published so far in this topic while it covers an existing gap regarding the use of agrivoltaics in vineyards in Crete. The results could be useful to farmers growing grapes, to policy makers, to public authorities and to energy companies that install photovoltaic systems.

### 2. LITERATURE SURVEY

The economic performance of agrivoltaics systems in vineyards has been assessed (1). The authors stated that under current conditions agrivoltaics are not economically viable for widespread adoption in Germany. They mentioned that inefficient revenue from combined grape and energy production leads to negative net-present values over 20-year period. The low-height vertical photovoltaic integration in vineyards has been examined (2). The authors tested experimentally low-height vertical photovoltaics in



three vineyards in southern Spain. They mentioned that these systems can operate in vineyards without significant differences in yield and grape composition. The use of agrivoltaics in grape farms in China has been studied (3). The authors stated that the use of agrivoltaics have positive economic impacts generating green electricity and maintaining approximately the same production of grapes. The benefits of agrivoltaics installed in vineyards in southern Spain have been explored (4). The authors stated that agrivoltaics: a) can enhance resilience and adaptability in agriculture to extreme weather events, b) improve productivity per unit area integrating renewable energies into farming, and c) contribute in less dependence on the grid and offer an additional income to farmers. The use of agrivoltaics in various crops with different photovoltaic technologies such as: conventional, bifacial, semi-transparent and concentrating systems has been studied (5). The authors stated that studies suggested that there are no universally optimal agrivoltaics configuration. The impacts of agrivoltaics on microclimate, water use efficiency and crop yield have been examined (6). The authors stated that agrivoltaics improve water use efficiency by 20-47%, lower air and soil temperature by 1-4°C and enhance crop resilience in water-scarce regions. However, they mentioned, lower yields are observed in light-dependent crops under high shading intensities. The shade tolerance of berries in agrivoltaics systems has been studied (7). The authors stated that low levels of shade are less detrimental to yield than high level of shade. They mentioned that several berry types are shade tolerant up to around 35% shade without yield loss. A description of an agrivoltaic system installed on vineyards has been published (8). It has been stated that the agrivoltaic system has nominal power at 970 kW<sub>p</sub> and is installed in two meters above ground level. It is also mentioned that it improves the water stress of the vines, protects the grapes from weather excesses, halves the wind speed and reduces the water use in irrigation up to 20%. The social perception of agrivoltaics systems in vineyards in South-eastern Spain has been assessed (9). The authors stated that there is a positive social perception from visitors in low-height agrivoltaics in vineyards. They mentioned that agrivoltaics is a viable solution reconciling agricultural and energy production. The performance of a grid connected photovoltaic system on the island of Crete, Greece has been analyzed (10). The authors stated that the nominal capacity of the solar-PV system was 171.36 kW<sub>p</sub>, the average annual solar-PV park energy output was 1,336.4 kWh/kW<sub>p</sub> and the average annual capacity factor was 15.26%. The use of agrivoltaics in vineyards has been examined (11). The authors stated that the benefits of agrivoltaics include: a) Improved land use efficiency, b) Crops' protection from light, water and temperature stress, and c) They keep the solar panels cooler increasing their efficiency. The use of agrivoltaics in the wine industry has been studied [12]. The authors stated that bifacial solar-PV modules can be used in vineyards generating electricity and exploiting the synergistic effect of growing plants and solar energy generation. The integration of solar-PV systems into German vineyards has been explored [13]. The authors stated that future solar-PV expansion should balance technical feasibility with social and environmental considerations. The authors presented a transparent GIS pre-screening framework for vineyards mentioning that the agronomical suitable size of agrivoltaics in vineyards can be up to 10 GW<sub>p</sub>. The effect of photovoltaic systems on berries production has been reviewed (14). The authors stated that integrating solar-PV systems in berry production offers a promising path towards sustainable and resilient agriculture. The use of agrivoltaics in vineyards in USA has been studied (15). The authors stated that the use of vertical solar-PV systems in vineyards is economically feasible demonstrating the synergistic effect of solar modules to agriculture. The use of agrivoltaics in fruit crop species has been reviewed (16). The authors stated that agrivoltaics have significant influence on fruit crops growth, yield and quality. They mentioned that findings indicate that a 30% shading prevents significant decline in fruit characteristics. The research trends in agrivoltaics have been studied (17). The authors stated that agrivoltaics is a new research area with the majority of the scientific publications are concentrated in the last three years. They also mentioned that actual business cases in agrivoltaics are required to assess and adopt them commercially by farmers. The potential of agrivoltaics in Mediterranean region has been examined (18). The authors estimated the transparency of PV modules that represents the area which is not occupied by solar cells at 0.57 to 0.71. They also evaluated the annual energy generation is several locations at 65.9 kWh/m<sup>2</sup>. Additionally, they mentioned that installing agrivoltaics systems into 1% of the total olive groves surface in the Mediterranean region would result in a 25% increase in the global solar-PV capacity and would generate 1.8% of the current electricity demand in selected Mediterranean countries. The impacts of agrivoltaics installed in vineyards have been explored (19). The authors stated that the installation of agrivoltaics reduced the incoming light by 47% while the reduction of the gas exchange rate and transpiration was only 7-9%. They also mentioned that solar panels caused a consistent ripening delay. The use of agrivoltaics in sustainable agriculture has been analyzed (20). The authors stated that agrivoltaics offer a sustainable model for land optimization. They mentioned that the future of large scale agrivoltaics depends on several factors such as: site specific design, tailored to crops and local conditions and the policy frameworks. The agrivoltaics as a new tool for electricity and food production have been examined



(21). The authors stated that the success of crops under agrivoltaics depends on many factors yet mainly on location and season. They proposed the definition of an optimal daily light integral for each species rather a shade level. The use of agrivoltaics in fruit crop species has been studied (22). The authors stated that analysis of current data suggests that a shading rate of 30% could be acceptable with fruit tree cultivation. They mentioned that limited data exist for grapes in semi-arid and arid regions strongly facing the climate change. The sustainability of vineyards with installed agrivoltaics systems has been explored (23). The authors stated that there is a broad consensus that quality of the wine growing landscape and the associated cultural heritage is greater than of agrivoltaics. The use of solar-PV systems in Crete meeting its power demand has been studied (24). The author stated that solar-PV systems installed on the 20% of the surface of rooftops in residential buildings can meet 18.52% of the annual electricity demand in the island. He also mentioned that floating solar-PVs installed on the surface in existing water reservoirs in Crete can meet 2.10% of Crete's annual electricity demand. The possibility of covering all the power demand in the island of Crete, Greece with solar photovoltaics has been investigated (25). The author stated that the nominal power of solar-PVs which could meet all the power demand in Crete is 2,333 MW<sub>p</sub>. He also mentioned that the required area for their installation is 4,660 ha which corresponds at 0.56% of Crete's total surface. The reshaping of the energy landscape of Crete through renewable energy valleys has been explored (26). The authors mentioned that renewable energy valleys represent a new concept concerning an energy hub for renewable energy generation, distribution and consumption. They mentioned that promotion of the idea of renewable energy valleys and energy storage technologies can accelerate the green energy transition in Crete. The solar energy potential in the MENA and Mediterranean regions has been assessed (27). The authors analyzed the global horizontal irradiance in eight zones stating that the annual electricity generation from solar-PV systems varied in the range of 1,344 kWh/kW<sub>p</sub> to 1,886 kWh/kW<sub>p</sub>. Four photovoltaic projects in Malta have been analyzed (28). The authors stated that the mean annual solar radiation in Malta is around 5 kWh/m<sup>2</sup> day while the mean monthly yield of the solar-PV systems was in the range of 2.76 kWh/kW<sub>p</sub> day to 3.61 kWh/kW<sub>p</sub> day. The development of green innovations in the wine industry has been examined (29). The authors analyzed data from 196 Spanish wine companies mentioning that employees in wine companies should be motivated to be creative in ecological terms developing environmentally friendly innovations. The technical and economic feasibility of a complete hybrid small modular reactor/hydrogen energy system has been analyzed (30). The authors stated that small modular reactors are nuclear reactors with small capacity producing zero-carbon emissions that can be coupled with hydrogen production. They estimated that the proposed system achieves a levelized cost of electricity between 0.046 €/kWh to 0.052 €/kWh. An effective and rational energy transition in Crete, Greece has been proposed (31). The authors stated that the core of the energy transition in Crete will be a set of fourteen wind parks and pumped-hydro storage systems as well as twelve heat and power co-generation plants. They mentioned that 100% clean energy transition in Crete is feasible while the payback period of the required energy investments is around ten years. The use of renewable energies in vineyards has been examined (32). The authors stated that the use of renewable energies in small scale can be profitable in both vineyards and wineries. They mentioned that the most used benign energies in this sector are solar thermal energy, photovoltaic energy and biomass.

### 3. USE OF SOLAR PHOTOVOLTAICS IN CRETE

Crete, the largest island of Greece, has emerged as a promising location for the development of solar photovoltaic energy systems. Its geographical position in the southern Mediterranean provides abundant solar radiation throughout the year, making it an ideal environment for harnessing solar power. As energy demand on the island continues to grow—driven by tourism, agriculture, and local consumption—the adoption of solar-PV technology offers a sustainable pathway to energy security and environmental protection. One of the main advantages of solar-PV in Crete is its potential to reduce dependence on imported fossil fuels. Historically, the island has relied heavily on oil-fired power plants, which are both costly and environmentally damaging. By expanding solar-PV installations, Crete can decrease greenhouse gas emissions and align with broader European climate goals. Moreover, decentralized solar systems, such as rooftop panels on homes and businesses, can help stabilize the local grid and reduce transmission losses. The economic benefits are also significant. Investment in solar-PV infrastructure creates job opportunities in installation, maintenance, and system design. Additionally, it supports local innovation and encourages the development of energy-related services. For farmers, solar energy can be particularly useful, as it enables cost-effective irrigation and reduces operational expenses. The combination of agriculture and solar—sometimes referred to as agrivoltaics—could be especially relevant in Crete, where land use is a critical issue.



However, challenges remain. The intermittent nature of solar energy requires effective energy storage solutions or complementary energy sources to ensure reliability. Crete's grid infrastructure has historically faced limitations in accommodating high levels of renewable energy, although recent upgrades and interconnection projects with mainland Greece are addressing these issues. Furthermore, careful planning is necessary to balance solar development with environmental conservation and landscape preservation, as large-scale solar farms can impact natural habitats and the island's visual appeal. Therefore, solar-PV technology represents a vital component of Crete's transition toward a cleaner and more resilient energy system. With its high solar potential, economic advantages, and alignment with sustainability goals, solar energy can significantly contribute to the island's future. By addressing technical and environmental challenges, Crete can serve as a model for renewable energy adoption in island regions worldwide. Table 1 indicates the electricity consumption by sector in Crete.

**Table 1. Annual electricity consumption by sector in Crete**

Sector	Annual electricity consumption (MWh)
Public buildings	237,519
Residential buildings	1,064,217
Primary sector	199,400
Industry	220,757
Tertiary sector	1,295,020
Public lighting	55,015
Miscellaneous	126,204
Total	3,198,132

Source: (30)

#### 4. VINEYARDS IN CRETE

Crete, the largest island in Greece, has a long and rich tradition of viticulture that dates back thousands of years. The island's unique combination of climate, soil, and topography makes it an ideal location for grape cultivation, particularly for wine production. Today, grape growing remains an essential part of Crete's agricultural economy and cultural identity, with both indigenous and international grape varieties thriving across its diverse landscapes. The climate of Crete plays a crucial role in grape production. Characterized by hot, dry summers and mild winters, the island provides optimal conditions for vines to grow and ripen. The abundance of sunlight ensures high sugar levels in grapes, which is essential for producing wines with strong flavors and good alcohol content. At the same time, cooling sea breezes and higher-altitude vineyards help maintain acidity, balancing the grapes and contributing to the complexity of the wines. Soil diversity is another important factor. Crete's vineyards are planted in a range of soil types, including limestone, clay and sandy soils. These variations influence the characteristics of the grapes, giving rise to a wide spectrum of wine styles. In mountainous regions, poorer soils and higher elevations often result in lower yields but more concentrated flavors, which are highly valued in winemaking. Crete is especially known for its indigenous grape varieties. Among the most prominent white grapes is Vilana, which produces fresh, aromatic wines with citrus and floral notes. Vidiano is another increasingly popular variety, known for its richer body and potential for aging. On the red side, Kotsifali and Mandilari are widely cultivated. Kotsifali tends to produce softer, fruitier wines, while Mandilari contributes deeper color and stronger tannins. Often, these grapes are blended to create balanced and complex wines. In addition to local varieties, international grapes such as Cabernet Sauvignon, Merlot, and Syrah have been introduced and adapted well to the Cretan environment. These varieties allow producers to experiment with different styles and appeal to global markets, while still maintaining a distinct regional character. Modern winemaking techniques have significantly improved the quality of Cretan wines. Many wineries now combine traditional methods with advanced technology, such as controlled fermentation and careful aging processes. This has led to greater consistency and higher-quality products that can compete internationally. Therefore, grape production in Crete is shaped by its favorable climate, varied soils, and rich heritage of indigenous grape varieties. The island's winemakers successfully blend tradition with innovation, producing wines that reflect both the history and the evolving future of Cretan viticulture. Table 2 indicates the area of vineyards in Crete, Greece.



**Table 2. Area of vineyards in Crete, Greece**

	2020	2015
Area of vineyards in Crete	22,184 ha	22,555 ha
%, Area of vineyards in Crete/Greece	21.55%	21.88%

Source: (33)

## 5. USE OF AGRIVOLTAICS

Agrivoltaics, the practice of combining agriculture with solar photovoltaic energy production on the same land, is emerging as an innovative solution to some of the most pressing challenges in food and energy systems. By integrating solar panels into farmland, agrivoltaics allows for the simultaneous cultivation of crops and generation of renewable energy, maximizing land-use efficiency and offering both environmental and economic benefits. At its core, agrivoltaics addresses the growing competition for land between agriculture and energy infrastructure. As global populations rise and demand for clean energy increases, land resources are becoming increasingly strained. Traditional solar farms often occupy large areas that could otherwise be used for farming. Agrivoltaics resolves this conflict by enabling dual land use, where crops grow beneath or between solar panels. This approach is particularly valuable in regions with limited arable land or high solar potential. One of the key advantages of agrivoltaics is its positive impact on crop productivity in certain conditions. Solar panels provide partial shading, which can reduce heat stress and limit water evaporation from the soil. This creates a microclimate that can benefit shade-tolerant crops such as leafy greens, herbs and some fruits. In arid or semi-arid environments, this shading effect can significantly improve water-use efficiency and crop resilience, making agriculture more sustainable under changing climate conditions. In addition to agricultural benefits, agrivoltaics contributes to renewable energy generation and climate change mitigation. The electricity produced by solar panels can be used directly on farms to power irrigation systems, machinery and storage facilities, reducing reliance on fossil fuels and lowering operational costs. Surplus energy can be fed into the grid, providing farmers with an additional source of income. This diversification of revenue streams enhances the economic stability of rural communities. However, agrivoltaics also presents challenges that must be carefully managed. The design and placement of solar panels require careful planning to ensure that crops receive sufficient sunlight. Not all crops are suitable for agrivoltaics while local climate, soil conditions and farming practices must be taken into account. Initial installation costs can be high, which may discourage small-scale farmers without access to financial support or incentives. Despite these challenges, technological advancements and increasing policy support are making agrivoltaics more accessible. Governments and research institutions are investing in pilot projects and developing guidelines to optimize system design. As awareness grows, agrivoltaics is gaining recognition as a viable strategy for sustainable development, particularly in regions vulnerable to climate change and resource scarcity. Therefore, agrivoltaics represents a forward-thinking approach to land management that aligns agricultural productivity with renewable energy generation. By making more efficient use of limited land resources, it offers a pathway toward a more sustainable and resilient future. With continued innovation and supportive policies, agrivoltaics has the potential to transform both farming and energy systems on a global scale.

## 6. POSSIBILITY OF USING AGRIVOLTAICS IN VINEYARDS IN CRETE

### 6.1 Use of agrivoltaics in vineyards

The integration of agrivoltaics into vineyards is an emerging global trend that reflects the need to balance agricultural production with renewable energy generation. Agrivoltaics—the co-location of crops and solar photovoltaic systems—offers a promising solution for viticulture, particularly as vineyards face increasing pressures from climate change, land scarcity and rising production costs. Across wine-producing regions in Europe, North America, and beyond, vineyard owners are beginning to explore how solar technology can complement traditional grape cultivation. One of the primary motivations for adopting agrivoltaics in vineyards is climate adaptation. Grapevines are highly sensitive to temperature, sunlight and water availability. Excessive heat and prolonged droughts can accelerate grape ripening, alter sugar and acidity levels, and ultimately affect wine quality. By installing elevated or strategically spaced solar panels above vine rows, growers can create partial shading that moderates extreme conditions. This microclimate can reduce heat stress, limit water evaporation and help maintain more stable growing conditions. Early studies in countries like France and Italy suggest that such systems can preserve grape quality while reducing irrigation needs. In addition to environmental benefits, agrivoltaics offers economic advantages for vineyard operators. Solar panels generate electricity that can



be used on-site for irrigation systems, processing facilities, and storage, reducing energy costs. In some cases, surplus energy can be sold back to the grid, providing an additional revenue stream. This diversification is particularly valuable in an industry that is often vulnerable to climate variability and market fluctuations. Globally, pilot projects and commercial implementations are expanding. In regions such as California, Germany, and Australia, vineyards are experimenting with different panel configurations, including adjustable systems that can optimize sunlight exposure throughout the day. These innovations aim to strike a balance between energy production and vine health, ensuring that neither function compromises the other. As technology advances and more data becomes available, agrivoltaics have the potential to become a standard practice in vineyards worldwide, supporting resilience and sustainability in a changing climate. Table 3 indicates the benefits of using agrivoltaics in vineyards while Table 4 the challenges in using agrivoltaics in vineyards.

**Table 3. Benefits of using agrivoltaics in vineyards**

1	Regulate the microclimate in vineyards
2	Reduce the excessive water losses
3	Generates electricity offering an additional income to farmers
4	Increase the resilience of vineyards in extreme weather events
5	Reduce the water needs in grapevines
6	Reduce the carbon emissions in vineyards producing on-site solar electricity
7	Reduce the dependence on the grid
8	Reduction of wind speed compared to conventional vineyards

Source: own estimations

**Table 4. Challenges in using agrivoltaics in vineyards**

1	Requires an upfront cost for the installation of the panels which might be prohibitive to small-size farm owners
2	Requires specific expertise to obtain the right balance between shade and sunlight which might be not available
3	Due to aesthetic and cultural considerations local communities may resist in these solar-PV installations

Source: own estimations

### 6.2 Use of agrivoltaics in vineyards in Crete

Agrivoltaics, offer a compelling solution tailored to the island’s conditions. Crete’s climate is characterized by abundant sunshine, making it highly suitable for solar energy generation. At the same time, vineyards on the island, often cultivating indigenous grape varieties such as Vidiano and Kotsifali, are increasingly exposed to heat stress and drought. Agrivoltaics can help mitigate these issues by installing elevated or semi-transparent solar panels above vine rows. These panels provide partial shading, reducing excessive solar radiation and lowering temperatures around the grape clusters. This moderated microclimate can slow down grape ripening, helping preserve acidity and aromatic complexity—key factors in wine quality. Water management is another critical concern in Cretan viticulture. With limited freshwater resources and growing competition from tourism and urban use, efficient irrigation is essential. Agrivoltaics can contribute by reducing soil evaporation and improving water-use efficiency. In addition to agricultural benefits, agrivoltaics introduces new economic opportunities. Solar panels installed in vineyards can generate electricity to power farm operations, including irrigation pumps, processing equipment, and storage facilities. Surplus energy can be fed into the grid, providing an additional income stream. This diversification is particularly valuable for small, family-owned vineyards that dominate Crete’s wine sector, helping them remain competitive in both domestic and international markets. However, the implementation of agrivoltaics in Cretan vineyards is not without challenges. The initial investment costs can be high, and access to financing or government incentives is crucial for widespread adoption. There are also concerns about landscape aesthetics, as vineyards contribute significantly to the island’s tourism appeal. Poorly designed installations could detract from the traditional scenery that visitors expect. Therefore, careful planning and design—such as maintaining low visual impact and respecting local architectural styles—are essential. Collaboration between agronomists, engineers, and local producers will be key to ensuring that agrivoltaic solutions are adapted to Crete’s unique conditions. Therefore, agrivoltaics offer a promising pathway for enhancing the



sustainability and resilience of vineyards in Crete. By integrating renewable energy with traditional agriculture, it supports environmental conservation, economic viability, and climate adaptation. With thoughtful implementation and continued research, agrivoltaics could play a significant role in shaping the future of Cretan viticulture.

6.3 Estimation of electricity generation from agrivoltaics installed in vineyards in Crete

For the estimation of the electricity generation from agrivoltaics installed in vineyards in Crete the following assumptions have been made:

1. The annual electricity generation by Solar-PV with nominal power 1 kW<sub>p</sub> in Crete is 1,500 kWh
2. Solar-PV with nominal power 1 kW<sub>p</sub> covers 6 m<sup>2</sup>
3. The annual electricity generation from solar-PV panels in Crete is 250 kWh/m<sup>2</sup>
4. The energy efficiency of mono-crystalline silicon solar-PV panels is 20%
5. The total area of vineyards in Crete is 22,184 ha (Table 2)
6. The area of Cretan vineyards covered by opaque solar-PV panels is 1% or 221.84 ha
7. The covered area by solar-PV in vineyards -in two scenarios - are 15% and 30%
8. The average annual electricity consumption per household is 4,000 kWh
9. The annual electricity demand in Crete is 3,198.13 GWh (Table 1)

The nominal power of the installed solar-PV systems and the electricity generated are estimated below.

The occupied area by opaque solar-PV panels in Cretan vineyards is 221.84 X 0.15 = 33.28 ha. The generated electricity by solar-PV installed in vineyards is 332,800 m<sup>2</sup> X 250 kWh/m<sup>2</sup> year = 83,200,000 kWh/year or 83.2 GWh/year. The nominal power of solar-PV panels installed is 332,800 (m<sup>2</sup>)/6 (m<sup>2</sup>/kW<sub>p</sub>) = 55.47 MW<sub>p</sub>. The number of households in Crete which can be powered by electricity generated in vineyards is 83,200,000 (kWh/year)/4,000 (kWh/year) = 20,800. The results of two scenarios with covered area by solar-PV panels in Cretan vineyards at 15% and 30% are presented in Table 5.

**Table 5. Electricity generation by agrivoltaics installed in Cretan vineyards in two scenarios with covered area by solar-PV panels in Cretan vineyards at 15% and 30%**

Total area of vineyards in Crete	22,184 ha	22,184 ha
Area of 1% of the vineyards in Crete	221.84 ha	221.85 ha
Covered area by solar-PV panels in Cretan vineyards	15%	30%
Nominal power of solar-PVs installed	55.47 MW <sub>p</sub>	110.94 MW <sub>p</sub>
Electricity generated by solar-PV installed in vineyards annually	83.2 GWh/year	166.4 GWh/year
Average annual electricity consumption per household	4,000 kWh	4,000 kWh
Number of households in Crete which can be powered by electricity generated in vineyards	20,800	41,600
Electricity generated by solar-PV installed in vineyards annually to total annual electricity demand in Crete	2.60%	5.2%

Source: own estimations

7. DISCUSSION

The possibility of using agrivoltaics in vineyards in Crete, Greece has been explored. It is stated that agrivoltaics is an emerging technology which allows the dual use of electricity and agricultural products. It has many benefits including the improvement in vineyards' microclimate, the higher resilience of vines, the reduction of water losses and the achievement of an additional income to farmers. Several studies indicate that the use of agrivoltaics in vineyards is economically profitable in USA, China and Spain while other studies conclude that it is not profitable in Germany. Several studies indicate that excess shading from solar modules affects crops' productivity. Other studies conclude that up to 30% shading does not significantly affect crops' productivity. Agrivoltaics can be installed vertically in vineyards without affecting significantly grapes' shading and productivity. Several solar photovoltaic technologies including conventional, bifacial, semi-transparent and concentrating systems have been experimented in vineyards. The social perception of agrivoltaics' installation in vineyards has been examined since they alter the landscape and the



cultural tradition related to winemaking. The most of the studies stated that the majority of local residents consider that agrivoltaics in vineyards are acceptable. Installation of agrivoltaics in vineyards can generate significant amounts of electricity. One study stated that coverage of 1% of olive groves area in several Mediterranean countries can produce electricity meeting 1.8% of their electricity demand. However, it is clear that more pilot studies and real-life projects should be implemented for better assessment of the impacts of agrivoltaics' installation in vineyards. Our results indicate that installation of agrivoltaics in vineyards in Crete can generate significant amounts of electricity. Our analysis does not consider the probability of reducing the yield and quality of grapes due to agrivoltaics installation which might affect their profitability in the crop. The accuracy of our results depends on the accuracy of the data used and the assumptions made. Future studies should be focused in the social perception of locals and tourists regarding the use of agrivoltaics in vineyards in Crete. It should be also focused in the design and implementation of pilot projects regarding the impacts of agrivoltaics in Cretan vineyards.

## 8. CONCLUSIONS

The current study investigated the possibility of using agrivoltaics in vineyards in Crete estimating the generated electricity. The main results can be summarized as follows:

- a) Use of agrivoltaics in several crops allows the simultaneous generation of electricity and agricultural products,
- b) Viticulture in Crete consists of an old traditional and historical cultivation while the island has abundant solar irradiance,
- c) There are several benefits and challenges regarding the use of agrivoltaics in vineyards,
- d) There are not many commercial agrivoltaics systems installed in vineyards worldwide and enough studies regarding their impacts on grapes' yield and quality,
- e) There are not published studies so far concerning the use of agrivoltaics in vineyards in Crete,
- f) Installation of agrivoltaics in vineyards in Crete covering 1% of their surface with coverage ratio at 15% and 30% can generate electricity meeting 2.6% and 5.2% of Crete' annual electricity demand respectively. The generated electricity can cover the electricity demand of 20,800 and 41,600 households respectively in Crete.

Our results could be useful to policy makers, to local authorities, to farmers, to winemaking industries and to companies promoting the use of solar-PV systems in the island.

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